Fermilab

$\bar{p}$ Note #360

Tevatron I Timing Scenarios and Clock Events

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1/6/84

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Jan. 6, 1984

TEVATRON I TIMING SCENARIOS and CLOCK EVENTS

Introduction

This note is a revision and combination of two previous notes: "Timing Scenarios" 4-29-83, and "Clock Events required by Tevatron I" 4-15-83. Part A of this note describes various timing scenarios envisioned for commissioning the Tevatron I project and carrying out Tevatron II (fixed target) and Tevatron I (collider) physics in the most efficient manner. Part B lists the TCLK events required to implement the scenarios described.

A -- TIMING SCENARIOS

Definitions:

ED = Energy Doubler
MR = Main Ring
B = Booster
D = Debuncher Ring
A = Accumulator Ring
P-line, AP-1, 120 GeV extraction
I-line, AP-2, 8 GeV pbar injection into D
T-line, D to A
E-line, AP-3, 8 GeV reverse injection A to MR(F17)
B-line, AP-4, 8 GeV, B to D.

There are four possible scenes:

I Fixed target physics using the ED

II Fixed target physics with parasitic PBAR studies.

1. 150 GeV protons
2. 120 GeV protons (bimodal MR ramp)
3. 8 GeV protons from the MR
   (a) Into the A.
   (b) Into the D.
4. 8 GeV protons directly from B to D.
5. Trimodal operation.

Trimodal operation allows both ED and MR beams to be sent to the fixed target areas at the same time parasitic pbar studies are in progress.

III Dedicated collider physics

IV Dedicated collider physics with parasitic use of the MR for testing beams and experiments in the experimental areas.

Although this note refers to 120 GeV and 150 GeV MR cycles, it seems likely that there will be only one MR energy, e. g. 140 GeV. The two cycle types will still differ in the length of the 8 GeV and flattop periods.

In the figures illustrating the various scenarios the clock events are shown as hex numbers enclosed by a circle. The definition of these events is in part B.

I Fixed Target Physics

To simplify the arithmetic in the examples, a one minute ED cycle and a 6 sec. MR cycle are assumed. These are shown in Fig. 1.

II Parasitic PBAR studies

150 GeV protons. Clearly if the MR were to ramp continuously with a 6 sec cycle there would be 9 unused MR ramps in between those needed for ED injection as shown in Figs. 2 and 4. Each MR cycle corresponds to 90 B cycles, or 900 B cycles total for one ED cycle. Resets are generated as follows: every 900 B cycles an ED master reset is issued. A MR reset is generated every 90 B cycles.

A possible 10 cycle sequence would be: ED-Null-7 PBAR-Null. Different MR reset events identify the different cycles. This gives 6 seconds to change conditions. If this is insufficient time then the sequence could be ED-2 Null-5 PBAR-2 Null, allowing 12 seconds to swap files and change conditions. Clearly, the time at 8 GeV can be lengthed and fewer 150 Gev ramps made per ED cycle.

In what follows we will call the two different MR cycles A and B. In no scenario described in this note do we envision needing more than two different MR cycles at one time. Trimodal operation is not considered in this note since it seems unlikely that it will occur.

What changes when switching from cycle A to cycle B? The first thing that must change is the B intensity. This is changed in two ways: (1) by changing the number of injected batches, (2) by changing the Linac pulse length. The B and 8 GeV line do not require retuning when reducing B intensity from 3-4 X 10**12. A range of 100X in intensity should be possible.

There are small effects of the ED ramp and fringing field on the MR. Work is in progress to eliminate these problems but if there is a residual interaction it may be necessary to change MR conditions depending on what portion of the ED cycle a given MR cycle occurs.

The MR may require slightly different tune (at low field) on the lower intensity cycles, when this is done using the Linac pulse length. These changes can be incorporated without resorting to the elaborate timing system used on the CERN P.S. The MR LLRF will, of course, change between cycle A and cycle B and a system will be designed to allow tuning cycle B without affecting cycle A operation. This system should go beyond the immediate goals of accelerator experiments and look forward to future operating requirements.

Use of the 150 GeV beam for TeV I RF studies

(a) PBAR production cycle. For studying the RF bunch rotation system, 150 GeV is as good as 120 GeV. Therefore on cycle B the sequence would be the following: (1) inject one batch (82-83 bunches) of variable intensity, 10**11 to 3 X 10**12 protons; (2) accelerate to 150 GeV; (3) do bunch rotation using the 53 mHz RF system (4) abort. This is illustrated in figs. 2 and 3.

(b) PBAR acceleration cycle. Here the sequence is more complicated: (1) inject 1 B batch; (2) kick out all but 13 bunches; (3) accelerate to 150 GeV (4) do bunch coalescing, rotation, recapturing, and narrowing using the h=53 (2.5 mHz) and h=1113 (53 mHz) RF systems. The current 400 msec flattop on the MR inject cycle is probably adequately long for these studies. This is shown in fig. 4 and rather schematically in fig. 5.

120 GeV protons, F17 extraction and targeting

A bimodal MR ramp is required as shown in Fig. 6. A "super-ramp" is set up and "learned". It is a repetitive sequence of A and B cycles that repeats every ED cycle. As mentioned previously the MR energies may be the same for the A and B cycle types. The A cycle is the normal MR inject cycle. The B cycle is the 2 second PBAR production cycle: (1) inject one B batch, (2) accelerate to 120 GeV, (3) extract at F17, (4) invert. If 2 seconds is sufficient for changing from A to B and from B to A, then the sequence would be: 6 sec inject cycle-2 sec null cycle-25 PBAR study cycles-2 sec null cycle. Clearly more null cycles can be inserted if more time is needed to change operating conditions.

Studies are needed to see how well the MR power supply responds to this pattern. One could start with a simpler pattern, alternating A and B cycles, even though only one A cycle/per ED cycle is needed.

8 GeV protons from the B around the MR to F17, extracted there and sent to the A.

This mode has the correct magnet polarity for pbars but incorrect direction for stochastic cooling.

This mode can be used parasitically and also in the next "scene" to tune up and check the A to MR line before it is used to transport pbars. The MR is held at 8 GeV. 8 GeV protons go around from A0 to F17 and are steered with an orbit bump into the extraction channel. Thus when returning to the regular inject cycle the dipole corrections have to be restored. This occurs every 1 to 2 seconds in the period between ED inject cycles and is called cycle B for purposes of the clock even though the MR is not ramping. The cycle B rate is determined by kicker reset times. Since the B intensity will differ on cycle A (inject cycle) and cycle B the procedure of inserting null cycles for file swapping as described above may be needed. This operation is illustrated in fig. 7.

8 GeV protons from the B around the MR, extracted at F17 and sent to the D.

Incorrect magnet polarity for pbars. Correct direction for stochastic cooling. Target can be removed or left in position to serve as an attenuator. This operation is similar to the above.

8 GeV protons from the B directly to the D.

Protons are extracted from B long straight section 3 and transported directly to the D. This operation can occur when the MR is not operating. Cycles could also be interleaved as in the previous scenarios. In that case, since the B intensity as well as the B extraction procedure will be different when extracting to the MR and when extracting to the D it will be necessary to define a cycle A and cycle B with enough null cycles in between for changing B operating conditions. This is illustrated in fig. 8. This figure shows beam injected into the D at 15 Hz. This rate may be too high but the figure is still applicable if it is understood that a certain number of null cycles may be inserted after each "16" cycle.

III Dedicated Collider Physics

The two cycles needed are:

(1) 2 second, 120 GeV PBAR production cycle
(2) a "standard" MR fill cycle.

The length of the standard MR fill cycle is determined mainly by the unstacking time from the A. Following is a possible MR standard fill cycle:

1.	unstack, estimate at least	10 secs.
2.	narrow bunch, 500 to 200 ns.	0.2 sec.
3.	rebunch at 53 mHz., 13 bunches.	24 msec.
4.	transfer A to MR incl. shutter	0.1 sec.
	....	
5.	accelerate to 150 GeV at 75 GeV/sec	2 secs.
	....	
6.	adiabatic coalescing at 150 GeV	0.1 secs.
7.	bunch rotation	0.2 secs.
8.	bunch narrowing	0.1 secs.
9.	transfer to ED	0.1 secs.
	....	
10.	invert	1 sec.

This adds up to roughly 11 secs at 8 Gev, 2 sec. ramp, 0.5 sec flattop, and 1 sec. invert as shown in Fig. 9.

Filling the ED.

The scenario can be described as follows. The MR has been cycling at the 2 sec, 120 GeV mode for several hours and pbars have accumulated in the A. Colliding beam physics has been going on in the ED for several hours and the luminosity is dropping. At this point it is decided to load new batches. The MR is switched from its 2 sec, 120 GeV pbar production cycle to its "standard" 15.5 sec. , 150 GeV fill cycle and learns this new cycle. The B is making null cycles. The protons and anti-protons in the ED are aborted. The ED is sitting at the 150 GeV level waiting to be loaded up. At this point the only place in the accelerator complex that has particles is the A.

The following operations are then done on successive MR cycles.

1. For 1 or more cycles, 8 GeV is injected from the B to MR, brought around to F17, run down the pbar injection line to the A. This checks the E-line.

2. For 1 or more cycles, 8 GeV is injected into the MR, accelerated to 150 GeV, injected into the ED, extracted from

the ED back into the MR (using the pbar line backwards) and aborted. This checks the forward and reverse injection lines from MR to ED.

3. For 3 or more cycles, 8 GeV pbars are injected into the ED. More than 3 cycles may be needed to achieve 3 high intensity batches injected at the proper phase. It is assumed that putting in a second batch on top of a bad first batch will not cause problems.

4. 8 GeV protons are injected into the MR, accelerated to 150 GeV, and injected in between the pbar batches in the ED. The present kicker pulse characteristics make it easier to inject pbars first. This may be accomplished with one MR cycle.

Each of the steps above will initiate a software/hardware timing sequence which is different in each case. When operations become routine, a master sequencer can cycle automatically between the steps listed above. A "perfect" ED injection sequence, as described, would be 6 cycles X 15.5 secs = about 1-1/2 minutes. This could possibly be shortened if there is a problem with leaving the pbars and protons circulating in the ED for several minutes at 150 GeV. The transfer line testing cycles do not have to 15.5 secs long. The proton injection cycle(s) can also be shorter. Doing this would mean that the time the MR stays at 8 GeV and at the 150 GeV flattop will change from cycle to cycle. This may, due to temperature effects, cause less than stable MR operation.

IV <u>Collider Physics with parasitic use of the MR</u>

In this scene an extraction system has been installed in the MR at A0 (since D0 will be in use for colliding beam physics). The running time is divided up into two kinds of periods that alternate:

1. Filling time. 10 - 30 minutes. This period includes filling the ED, accelerating, turning on the low-beta insertion(s), and establishing stable conditions for colliding beam physics. During this period the MR fixed target operation is disabled.

2. Colliding Beam Physics. Several hours. During this period fixed target operation of the MR is interleaved with pbar production.

Figure 10 illustrates one example of how this could be accomplished. Some of the time is taken away from pbar production and used to send beam out to the experimental areas for testing beam lines and experiments. In the sequence shown the A cycle (higher priority) is the 2 sec. pbar production cycle and the B cycle is a 1.5 sec, 150 GeV, slow spill every 30 seconds. The maximum energy of the fixed target cycle is determined by the B0 overpass. If a 2 sec null cycle before and after the 5 second fixed target cycle is sufficient for swapping conditions then the sequence is A(null)-B(fixed target)-A(null)-8 X A(pbar). 36% of the potential pbar production time is lost. The slow spill duty cycle is 6%.

Summary of Booster cycles

Presently there are 3 types of Booster cycles:

1. Null

2. Prepulse (no beam)

3. Beam

To implement the scenarios described more types are necessary since the intensity and extraction requirements will vary:

1. Null

2. Prepulse (no beam)

3. Beam (MR cycle A)

4. Beam (MR cycle B)

5. Beam directly to D or A using MR as beam transport

6. Beam directly from B to D (using B-line)

Neutron Therapy Facility

In all of the scenarios described there are many B null cycles available for switching the Linac to Neutron Therapy. However, because of the exclusive use (or interleaving) of 2 second MR cycles, that switching will have to occur more rapidly than at present in order to provide sufficient beam time to NTF. Such modifications also reduce patient treatment time. The power supply running the 58 degree bending magnet can be converted to bipolar operation thus reducing fall time. The magnet can probably be run at higher voltage and the regulation circuit modified to reach the stable full on and full off levels more rapidly.

B -- CLOCK EVENTS REQUIRED BY TEVATRON I

Tevatron Clock Events are assigned by R.J. Ducar. His most recent list of clock event assignments is given in Controls Hardware Release No. 17.6, October 23, 1983. In that note 57 events are defined.

This note is a list of required Tev I clock events. Some presently assigned clock events are not needed; in other cases definitions need to be modified.

Following are the categories in which changes, additions, and deletions are proposed:

	Event Numbers (Hex)	Categories
	10 - 1F	Booster
MAIN RING	20 - 2F	Existing Main Ring
	2B - 2F	MR BPM system
	80 - 8F	PBAR production cycle
	90 - 9F	PBAR and proton inject cycle
PBAR SOURCE	A0 - AF	Accumulator
	D0 - DF	Debuncher

BOOSTER

The Booster presently has assigned four different reset events. Two additional Booster reset events are needed to accomplish the various scenarios envisioned. All six of these events are listed below for completeness.

Booster Reset for Null cycle, 11 -

Booster systems null cycle. Signals the beginning of a 66 msec. booster cycle during which beam will not be accelerated.

Booster Reset for Beam Pre-pulse cycle, 12 -

Booster systems reset for a beam pre-pulse cycle during which beam will not be accelerated. Pulsed devices generally decode this as if it were a beam cycle in order that they reach stable operating levels.

Booster Reset for Accelerated Beam to MR, Cycle A, 13 -

Booster systems reset for an injected beam cycle into MR cycle type A. Protons accelerated in this cycle end up either in the ED for fixed target operation or in the parasitic mode where MR beam is extracted to the experimental areas.

Booster Reset for Accelerated Beam to MR, Cycle B, 14 -

Booster systems reset for an injected beam cycle into MR cycle type B. Protons accelerated in this cycle end up either for pbar production (MR cycle clock events 80, 81 etc.) or for pbar/proton acceleration and injection into the ED (MR cycle clock events 90, 91 etc.).

Booster Reset for Accelerated Beam to P-Bar, 15 -

This event will be used when Booster beam is sent 3/4 of the way around the MR and extracted at F17. Beam can then be steered either to the A ring or the D ring.

Booster Reset for Accelerated Beam to P-Bar, 16 -

This event will be used when Booster beam is sent directly to the Debuncher ring.

MAIN RING

The basic clock cycle is set by the ED. It is assumed that for some purposes (parasitic pbar studies, parasitic use of the MR during ED collider physics) it is necessary to divide the ED cycle into a sequence of MR cycles of two types, called cycle A and cycle B. It is also assumed that at no time will more than two types of cycle be needed. The clock events for MR cycle A are already assigned: 20, 21, 22, 23, 24, 25, 26. Events 23, 24 (front porch) are no longer needed. Additional clock events are needed for cycle B.

<u>New Main Ring BPM system</u>

Prepare for Beam, 2B -

This event is similar to 71 in the ED system.

Write Profile Memory, 2C -

This event is similar to 75 in the ED system.

Write Display Frame, 2D -

This event is similar to 78 in the ED system.

Flash Trigger, 2E -

This event is similar to 77 in the ED system.

PBAR Production Cycle

Main Ring Reset for Null Cycle B, 80 -

This event signals the reset of a Main Ring null cycle (no beam). It is used to arm devices that will be used in subsequent cycles for cycle B pbar production by the MR. If it follows a 21 (cycle A, beam) cycle it is used by the hardware and software to load new files into the Booster and MR to prepare for cycle B operation. If it follows an 81 cycle (cycle B, beam) it is used by the hardware and software to load new files into the Booster and MR to prepare to switch back to cycle A operation.

Main Ring Reset for Accelerated Beam, cycle B. 81 -

Cycle reset (follows injector program reset delay). Cycle period can be set with a resolution of 1 Booster cycle. This event signals the beginning of an accelerated beam cycle to provide protons for pbar production studies.

Main Ring Start of Ramp, cycle B. 82 -

Start of ramp, calculated by the MR power supply waveform specification program.

Main Ring Pbar Device prepulse, cycle B. 83 -

is a clock event occurring shortly before MR flattop (85 and 86) and is used to arm devices in the pbar system.

Main Ring Start of Flat Top, cycle B, 85 -

Start flat-top calculated by the MR power supply control program. Can be used to start the MR RF program.

Main Ring End of Flat Top, cycle B, 86 -

End flat-top calculated by the MR power supply control program.

Main Ring pbar/proton acceleration

Main Ring Reset for Null Cycle B, 90 -

This event is similar to 80 except it is for cycle B - pbar/proton acceleration.

Main Ring Reset for Accelerated Beam, cycle B. 91 -

Similar to 81 except it signals a MR cycle in which either protons or pbars will be accelerated for injection into the ED.

Main Ring Start of Ramp, cycle B. 92 -

Similar to 22 or 82.

Main Ring Pbar Device prepulse, cycle B. 93 -

This event occurs shortly before MR flattop (95 and 96) and is used to arm devices in the pbar system for a pbar/proton acceleration cycle.

MR Standard Fill cycle, unstacking complete, 94 -

The standard fill cycle will be used for 10-30 minutes to load up the ED with protons and anti-protons. It is is defined with the events 90,91,92,93,95,96. Event 93 occurs shortly before flat top begins. Since the unstacking time is long (> 10 seconds), it is useful to insert an additional event between 91 and 92 marking unstacking complete.

Main Ring Start of Flat Top, cycle B, 95 -

Similar to 25 and 85. Can be used to start the MR RF programs.

Main Ring End of Flat Top, cycle B, 96 -

Similar to 26 and 86.

Comments on existing MR clock events:

Main Ring Injected Beam Synch, 28 -

This event occurs between 21 and 22, between 81 and 82, or between 91 and 92. It can be used in either cycle A or cycle B.

MR Reset for Accelerated Beam to the P-bar target, 29 -

This clock event is no longer needed. When p-bars are produced cycle B will be used and will be defined by clock events 80, 81, 82, 83, 85, 86.

MR Reset for Accelerated Fixed-target Beam, 2A -

Fixed target beam from the MR would be a parasitic activity during periods of pbar production and colliding beam physics. Pbar production would be done on cycle B defined by clock events 80,81,82,83,85,86. Fixed target operation would be done on cycle A defined by clock events 20, 21, 22, 25, and 26. Therefore clock event 2A is unnecessary.

ACCUMULATOR --

BPM Prepare for Beam, A1 -

Upon receipt of this event, all BPM systems in the A will inhibit self-testing operations and prepare for beam passage. This event should precede beam by at least 200 msec. This event can also be used to synchronize the microprocessors in the beam line beam profile monitors. Those microprocessors will locally generate gate width, sampling frequency, and number of pulses to integrate before resetting.

BPM Write Profile Memory, A5 -

This event will write the next 20 byte snapshot frame into the non-circular profile memory for the BPM system in the A.

BPM Flash Trigger, A7 -

This event will be encoded a fixed time after receipt of a signal by the encoding hardware. It will be transmitted with a jitter not exceeding one clock lsb. This event, with appropriate delays and gate widths generated in the microprocessors of the Accumulator BPM system will sample, hold and digitize a single pass beam poisiton and intensity.

Variable Event, AC -

This event is set from an applications page and is used to read any device (for example a correction coil current) in the A at a fixed time in each cycle.

DEBUNCHER --

BPM Prepare for Beam, D1 -

Upon receipt of this event, all BPM systems in the D will inhibit self-testing operations and prepare for beam passage. This event should precede beam by at least 200 msec.

BPM Write Profile Memory, D5 -

This event will write the next 20 byte snapshot frame into the non-circular profile memory for the BPM system in the D.

BLM Write Display Frame, D6 -

This event is used to signal all the loss monitor systems to record loss measurements in their local buffer memoryies. Although this event is listed under D clock events, it can be used for loss monitors anywhere in the source (including beam lines).

BPM Flash Trigger, D7 -

This event will be encoded a fixed time after receipt of a signal by the encoding hardware. It will be transmitted with a jitter not exceeding one clock lsb. This event, with appropriate delays and gate widths generated in the microprocessors of the Debuncher BPM system will sample, hold and digitize a single pass beam poisiton and intensity.

Variable Event, DC -

This event is set from an applications page and is used to read any device (for example a correction coil current) in the D at a fixed time in each cycle.

SUMMARY

28 New Clock events needed:

B -- additional resets: 15, 16

MR -- BPM system: 2B, 2C, 2D, 2E

MR -- pbar production: 80, 81, 82, 83, 85, 86

MR -- pbar acceleration: 90, 91, 92, 93, 94, 95, 96

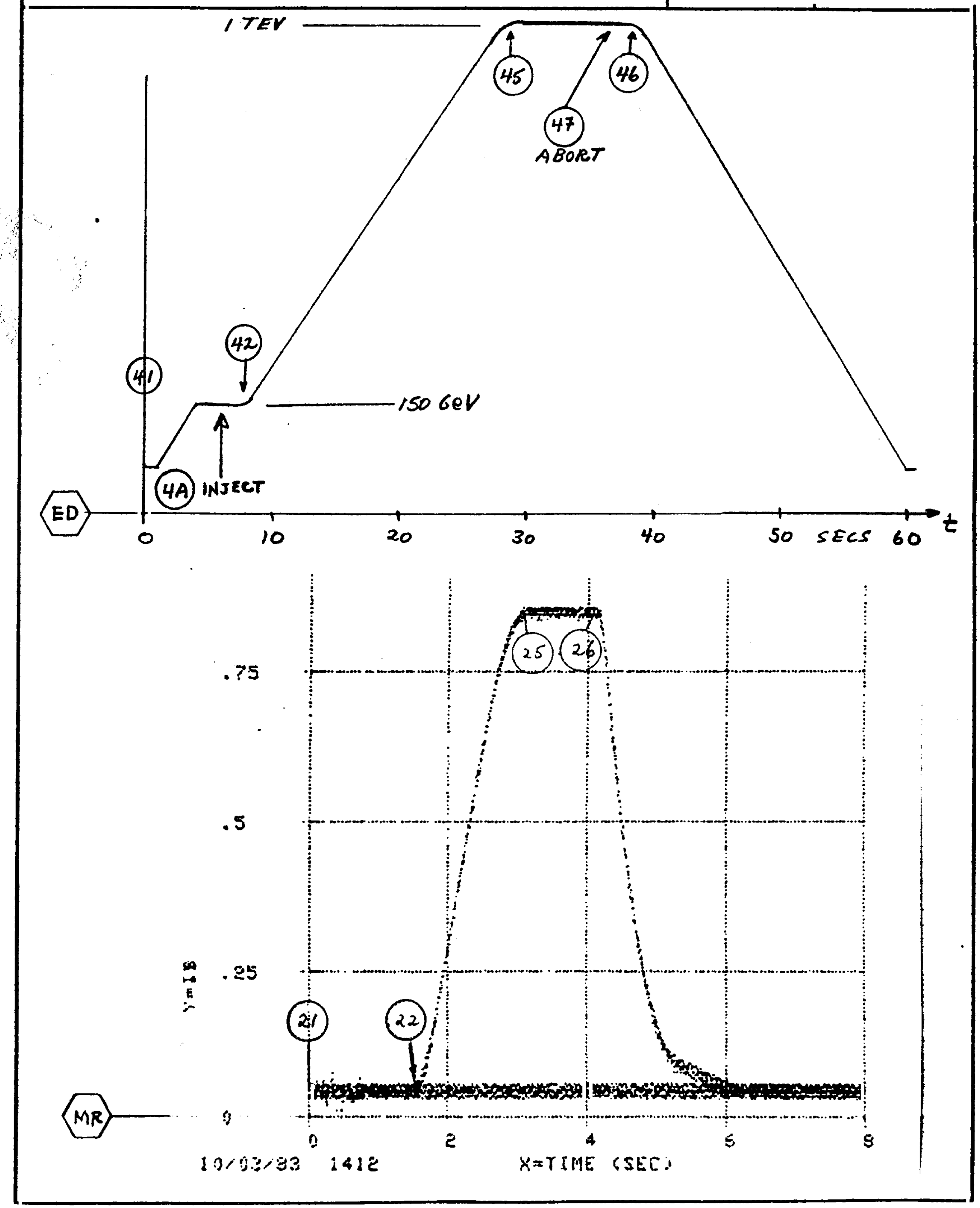
A -- BPM system: A1, A5, A7; Variable: AC

D -- BPM system: D1, D5, D7; BLM: D6; Variable: DC

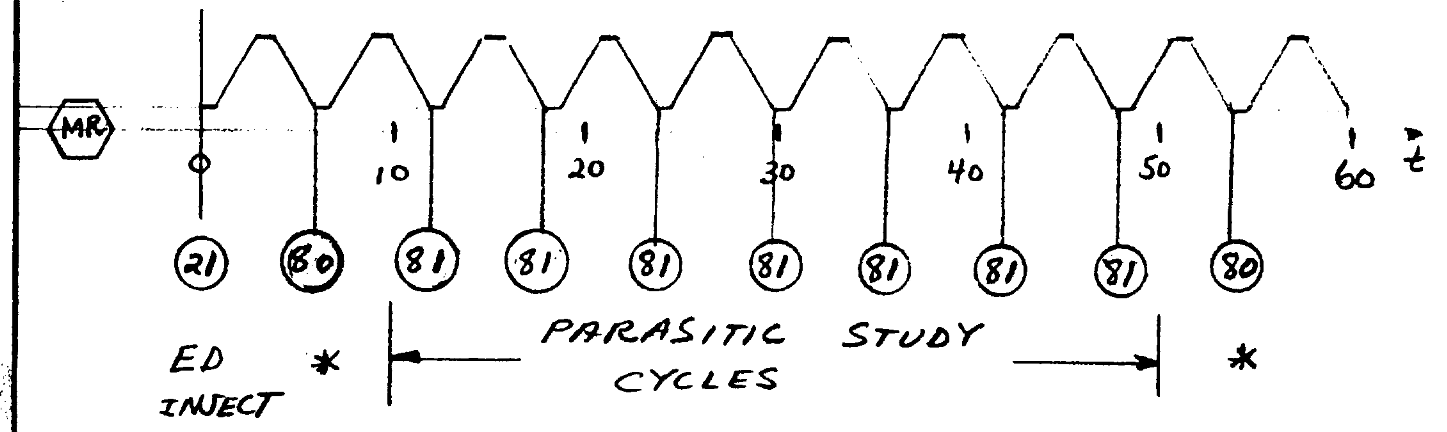
4 Present clock events not needed:

23, 24, 29, 2A

FIG. 1 NORMAL FIXED TARGET OPERATION



PARASITIC PBAR STUDIES



* CYCLES FOR CHANGING CONDITIONS (IF NECESSARY)

FIGURE 2

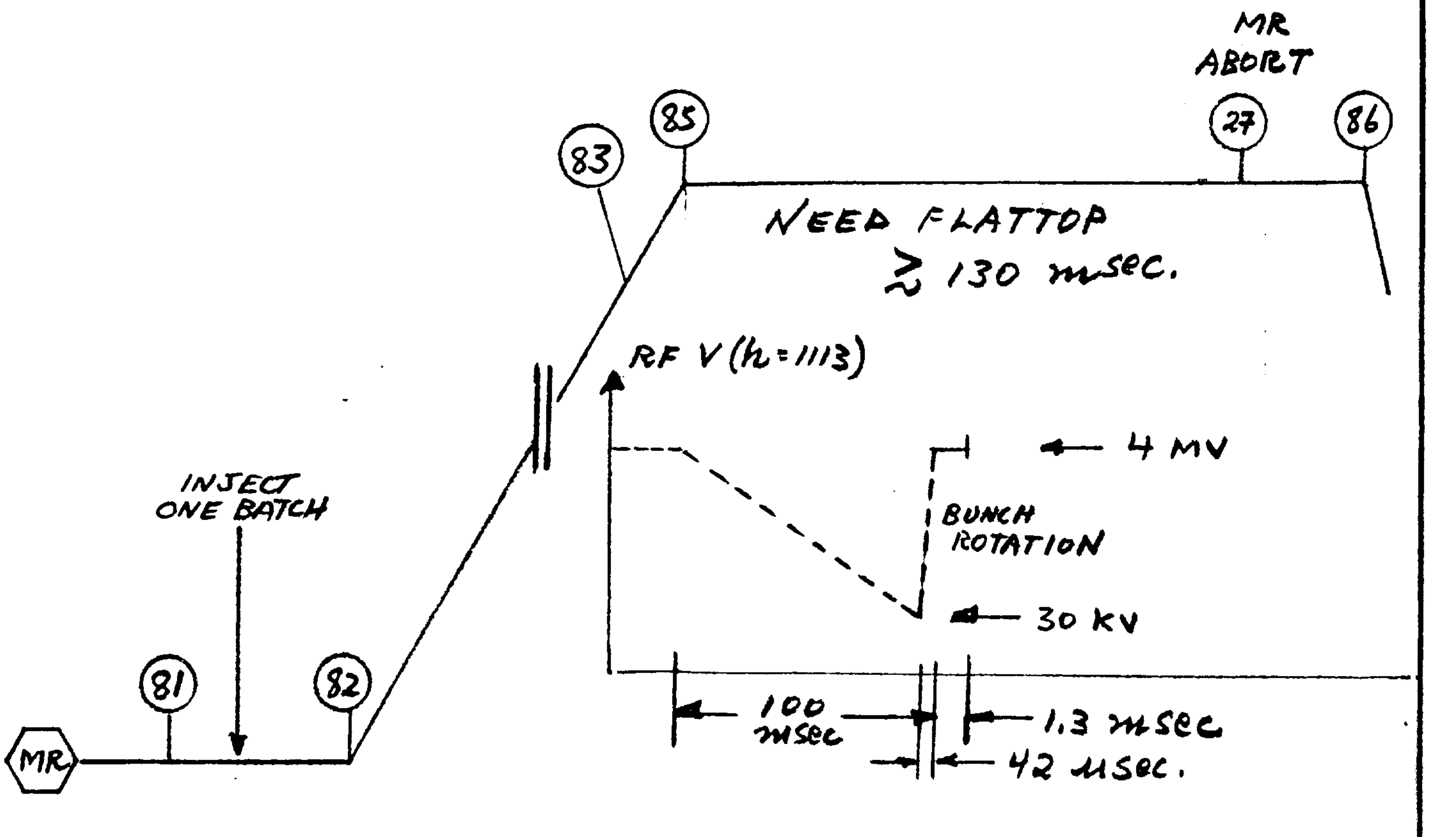
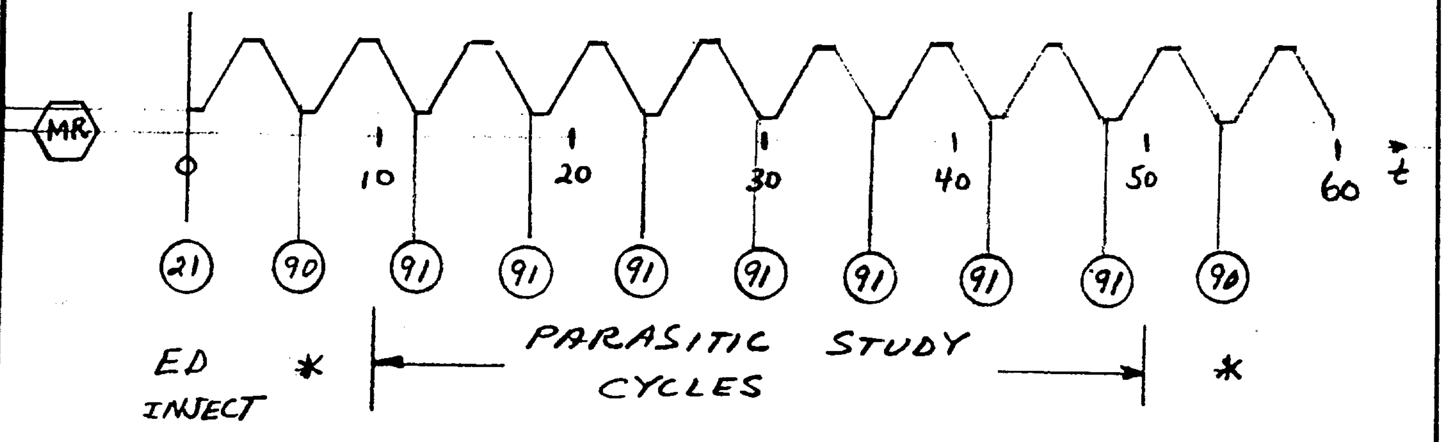


FIGURE 3 NOT TO SCALE

PARASITIC PBAR STUDIES



* CYCLES FOR CHANGING CONDITIONS (IF NECESSARY)

FIGURE 4

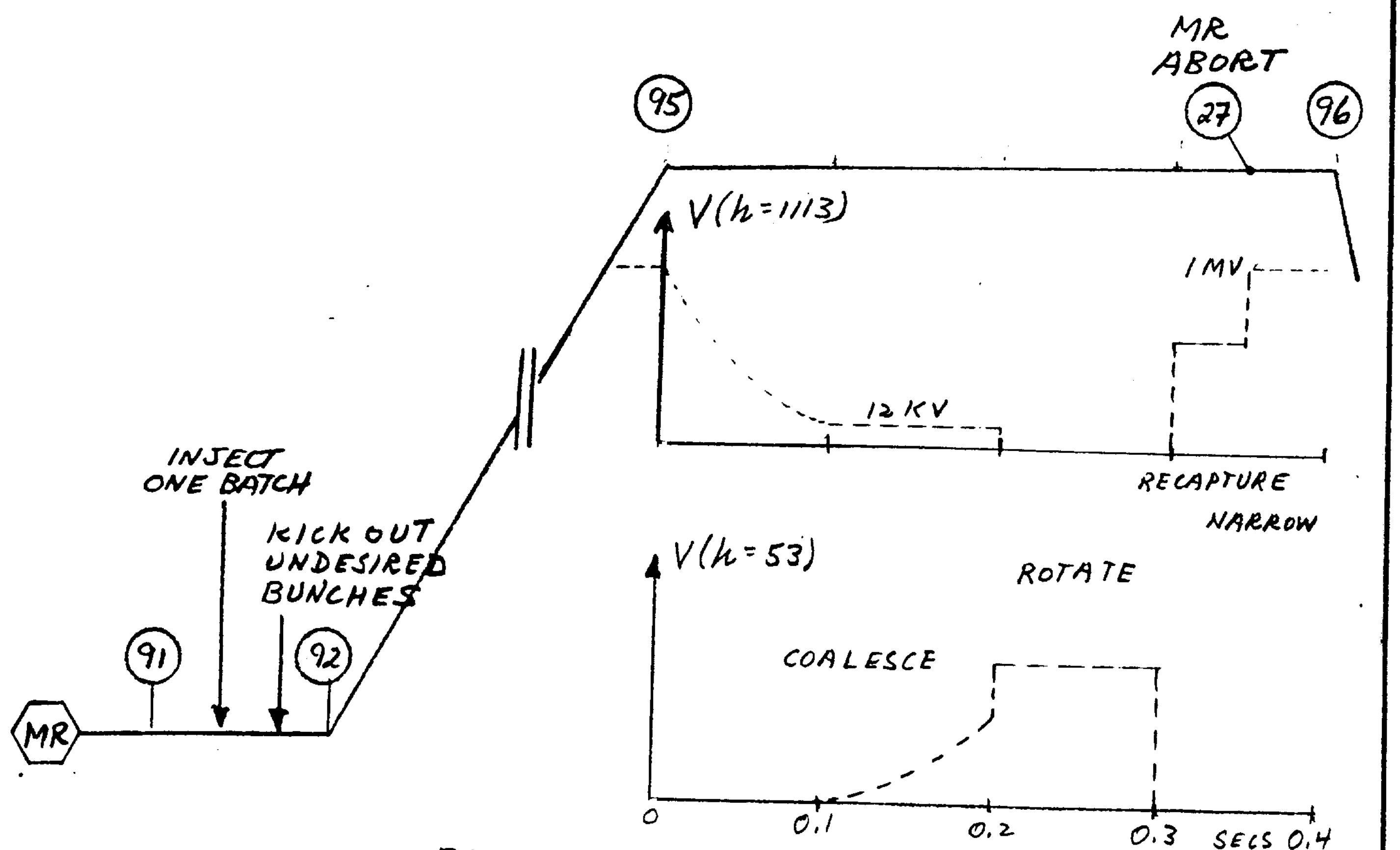


FIGURE 5 NOT TO SCALE

PARASITIC PBAR STUDIES

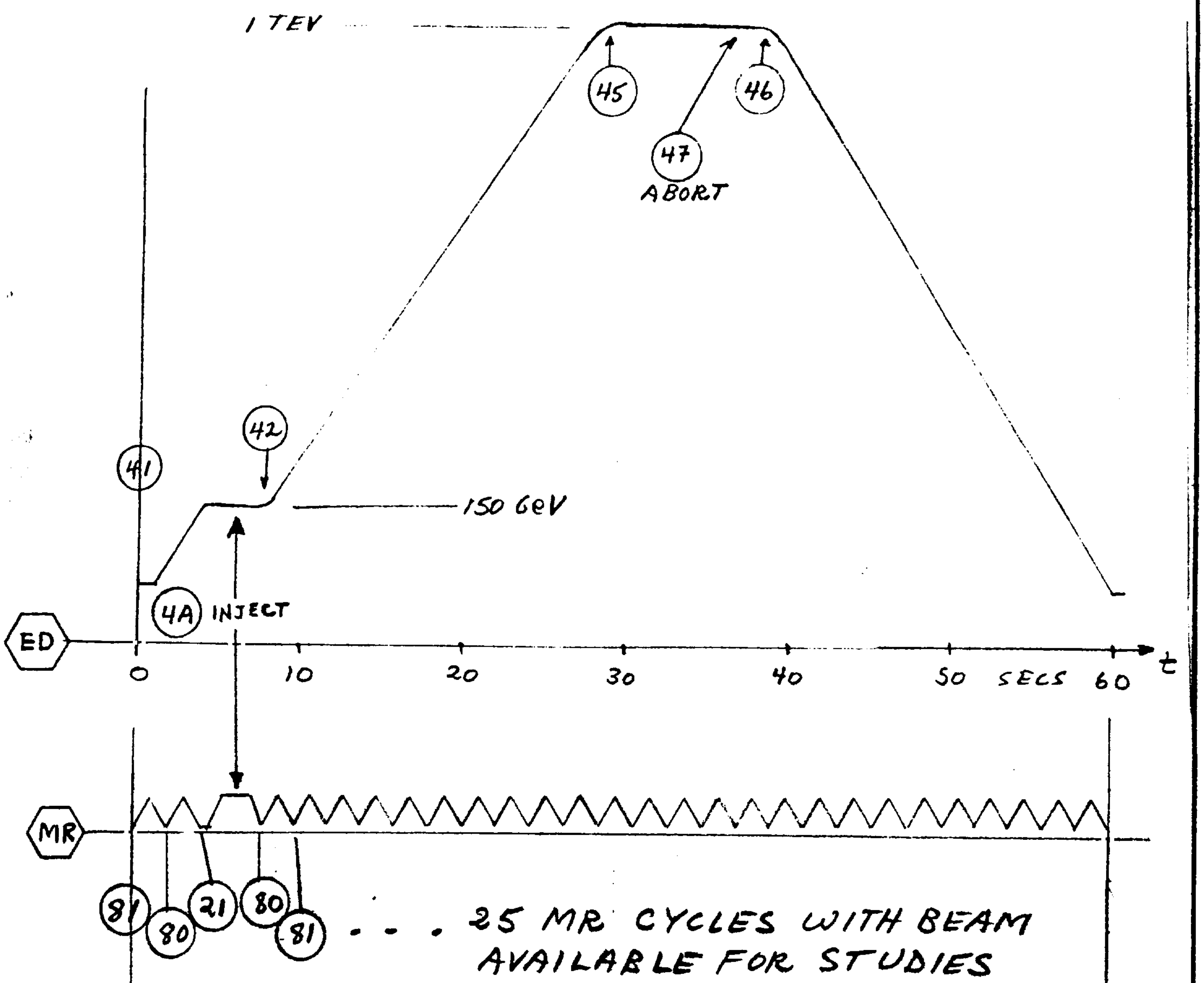


FIG. 6 TARGETING

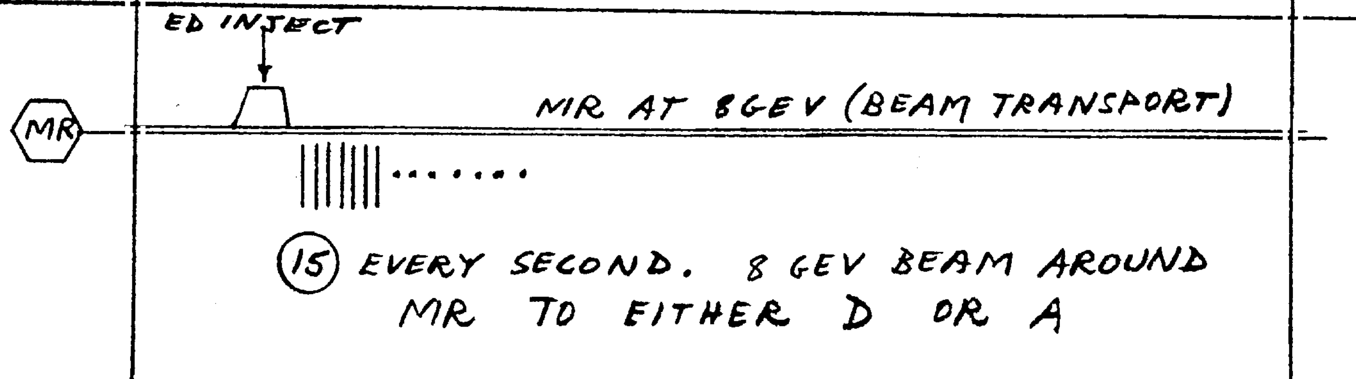


FIG. 7 COMMISSIONING WITH PROTONS

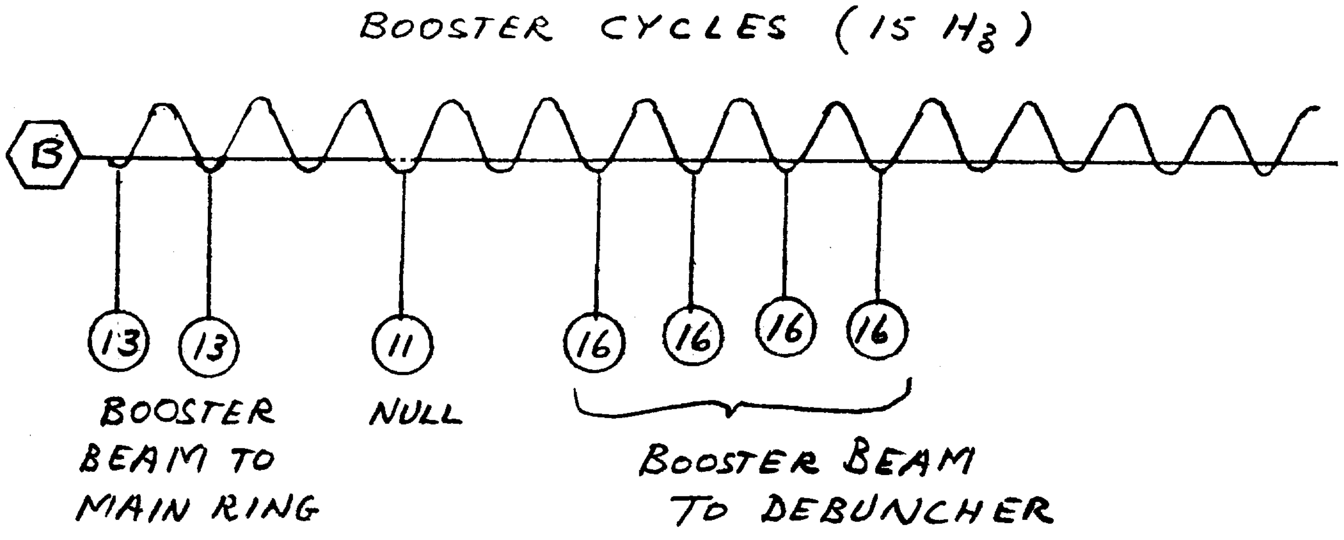


FIGURE 8

FIGURE 9 STANDARD MAIN RING FILL CYCLE

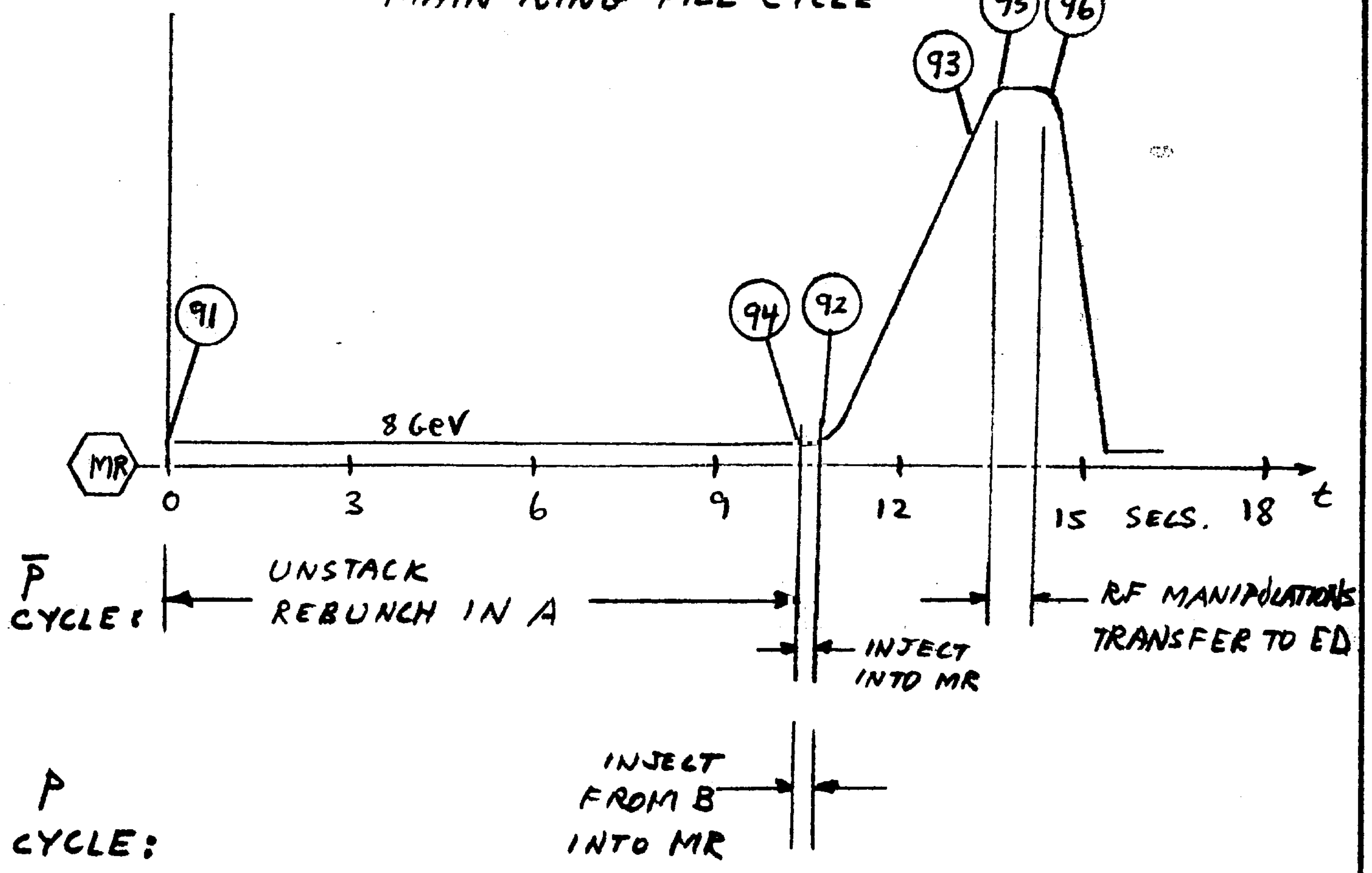
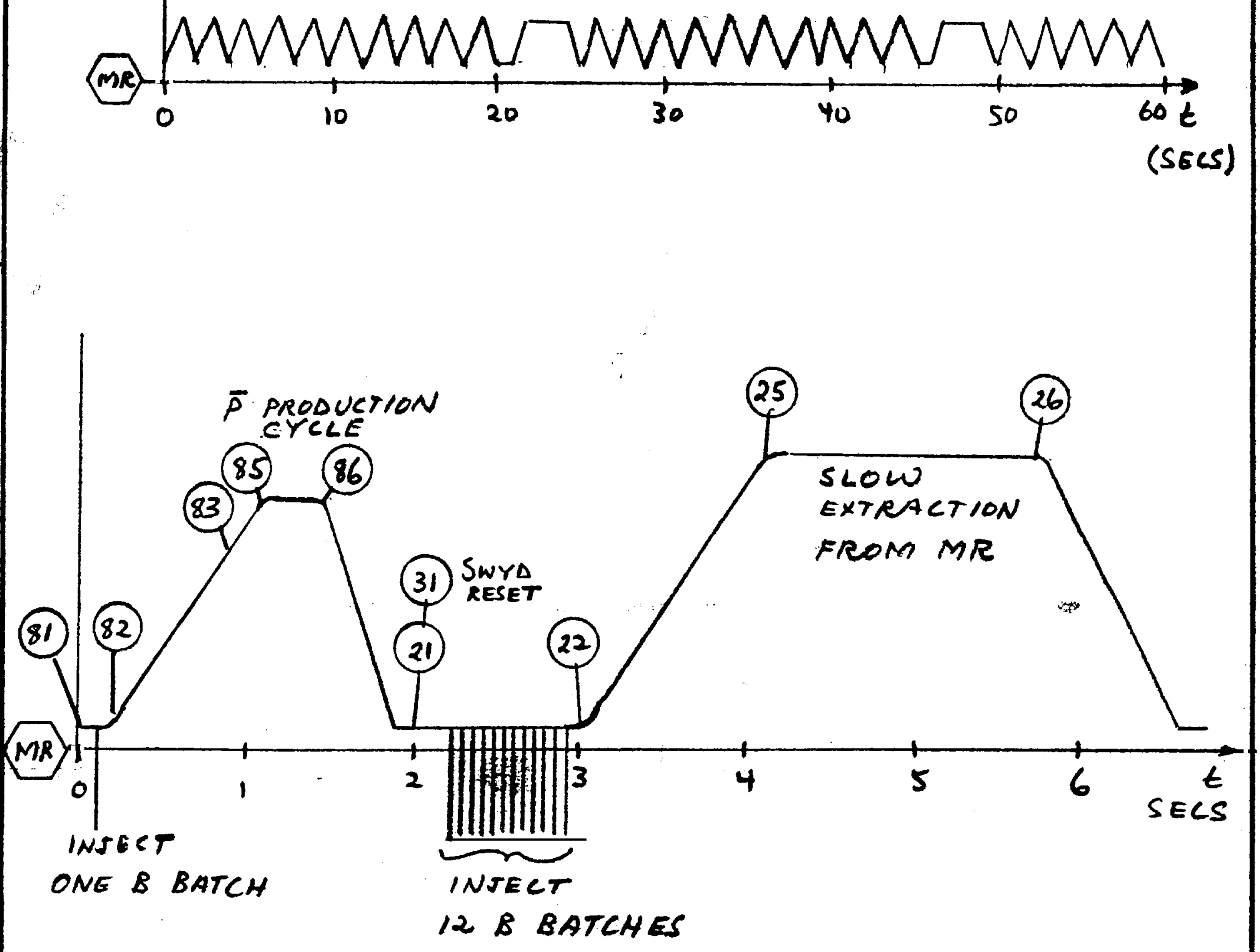


FIGURE 10. PARASITIC MR BEAM TO EXPERIMENTAL AREAS



CLOCK EVTS 21, 22, 25, 26 SENT TO EXPTL AREAS